A POWER CONVERTER OVERVIEW FOR THE DIAMOND STORAGE RING MAGNETS.

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Abstract

This paper introduces the power converter requirements for DIAMOND, the new 3 GeV Synchrotron Light Source for the UK. It presents a summary of the different topologies and configurations considered for the storage ring magnet power converters. The cabling options, ac distribution considerations, controls and thermal management issues have been addressed, with reference to design solutions chosen by other similar new facilities. A performance overview is also included, along with a project plan of the future development and investigation required.

1 INTRODUCTION

The storage ring magnet power converters are, with the exception of the injection elements, dc supplies. All the power converters are rated for 3 GeV operation plus a 10% safety factor on both current and voltage, plus an additional 5% on the voltage to allow for cable voltage drop. The DIAMOND storage ring lattice shown in Fig. 1; has a 24 cell configuration, consisting of:

- 2 dipole magnet;
- 10 quadrupole magnets;
- 7 sextupole magnets;
- 35 slow dynamic correctors;
- 8 fast dynamic correctors.

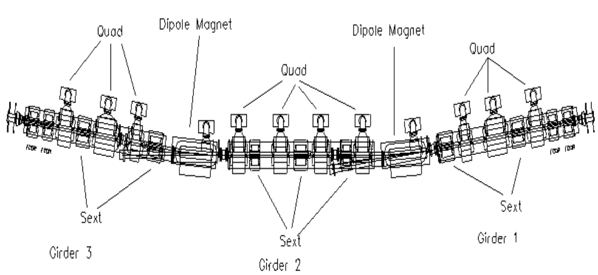

Figure 1: Typical Cell Arrangement

The power converters for the dipole, quadrupole and sextupole are all unipolar (1 quadrant), as opposed to the correction power supplies, which are 4 quadrant. For each cell of the storage ring there is an associated Control Instrumentation Area (CIA). These house racks for magnet power supplies, vacuum pump supplies and control and instrumentation equipment. The high power rating of the dipole converter cannot be supplied from the CIA and will be located in a separate room.

The dipole magnets are connected as a series string and will only require a single high power current converter. The quadrupole and sextupole magnets are individually powered, to provide optimum versatility in adjusting the lattice functions in the insertion regions. This arrangement has a large impact on cost, with a total of 408 individual converters required.

2 POWER CONVERTER RATINGS

Table 1: Storage ring magnet power converter ratings

Family	No. per family	Volts (V)	Current (A)	Power (kW) per magnet	Total power (kW) per Family
Dipole	48	462.92	1470.5	20.44	681.0
Q1AB	36	19.44	200.0	3.89	139.9
Q2AB	36	18.43	200.0	3.68	132.6
Q1B	36	18.43	200.0	3.68	132.6
Q2B	36	24.61	200.0	4.92	177.1
Q3B	36	15.32	200.0	3.07	110.4
Q1AD	12	19.44	200.0	3.89	46.6
Q2AD	12	18.43	200.0	3.68	44.2
Q1D	12	18.43	200.0	3.68	44.2
Q2D	12	24.61	200.0	4.92	59.0
Q3D	12	15.32	200.0	3.07	36.8
S1A	24	15.3	100	1.55	37.1
S2A	48	11.4	100	1.15	55.3
S1B	36	15.3	100	1.55	55.6
S2B	36	15.3	100	1.55	55.6
S1D	12	15.3	100	1.55	18.5
S2D	12	15.3	100	1.55	18.5

The current ratings shown in Table 1, were optimised to ensure a balance between simplification and feasibility of the magnet design, against minimising the losses in the cable and power converter efficiencies [1]. Each magnet family has the same design current, but may have a different design voltage. This allows common power converter units to be specified, minimising spares and simplifing replaceability. It is envisaged that the power ratings for the individual units will be 6kW for the quadrupole magnets and 2kW for the sextupole magnets.

The additional power rating for the quadrupole, will allow the output voltage limits to be increased. This can then be used for beam based alignment exercises which have proved very successful on the SRS and at other accelerators.

The need for such a large number of low power <6kW power converters means that the manufacture, test, installation and commissioning will require major resources. To minimise these resources during manufacture and test, complete systems will be specified. It is envisaged that fully equipped power converter racks that include ac distribution, controls and thermal management will be delivered. Their performance specification figures are shown in Table 2; these are gauged on that required by other new accelerators. The figures will be revised before the final tender exercise, taking into account the filtering effects of the vacuum chamber and the magnets. The ripple frequency and amplitude will depend on the power converter technology employed.

Table 2:Power converter performance specification

Performance	Dipole & Quadrupole	Sextupole
Type	Unipolar	Unipolar
Stability (8 hrs)	± 10 ppm	± 50ppm
Reproducibility (cyclic)	± 20ppm	± 100ppm
Accuracy (1 year)	± 50ppm	± 200ppm
Resolution (min)	18 bit (5ppm)	16 bit (15ppm)
Ripple 50Hz (300Hz)	50mV (300mV), 3mV (20mV)	3mV (20mV)
Operating Range	10 – 100%	10 – 100%

3 POWER CONVERTER TOPOLOGIES

3.1 Dipole

After consultation with manufacturers there will be two topologies considered, the most popular being the line-commutated thyristor with active filter, the other is a switchmode (chopper) design.

The line-commutated thyristor converter is a simple technology that is well understood. Its power factor depends on the thyristor firing angle, but even optimised only 0.75 is realistic. The specification will quote a power factor better than 0.95, ensuring that correction is included in the manufacturer's proposal. Its high operating efficiency will reduce running costs and loading on the thermal management system.

The switch-mode technology may consist of a series and/or parallel connection of a number of lower power modules rated at 50 or 100kWatts each. The efficiency is good, but will incur higher running costs and loading on the thermal management system. The harmonics on the input supply must be minimised, with careful consideration to the input filtering, but power factor is close to unity.

3.2 Quadrupole and Sextupole

The soft switchmode converter is considered the most suitable solution for the storage ring quadrupole and sextupole magnets. It offers a compact solution that is modular and light-weight, requiring minimal installation space that simplifies replaceability.

The specification will not make any distinction between common or individual input stages as they are both viable options. The common input was preferred choice of the Canadian Light Source (CLS), but can present switching problems at the dc bus and generate high fault currents. If used for DIAMOND then a twelve pulse rectifier configurations would be required, to minimise the harmonics and gain the benefit of incorporating a transformer. The individual input offers complete independence, and switching occurs at the ac network. This will provide a complete modular solution as no additional rack is required for the dc central source.

4 CABLING ISSUES

The voltage drop in cables from the CIA to each magnet, have non-negligible effects. The access arrangements (labyrinths) into the Storage Ring tunnel and the cable cross sectional area, determine both the voltage drop and the power loss in each cable.

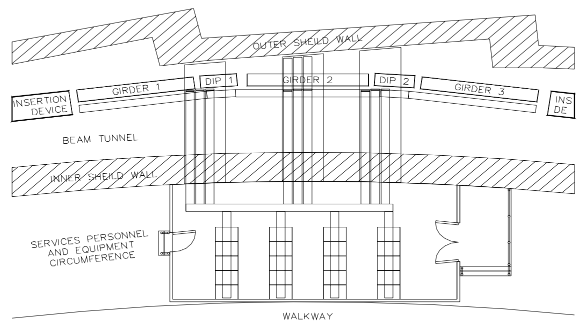

Figure 2: Storage ring - three labyrinth option

A number of labyrinth options for each cell have been considered:

- a single large labyrinth aligned with the centre of girder 2;
- two labyrinth design positioned opposite each dipole;
- three labyrinth design, which is a combination of the two above solutions.

After comparing cable length, voltage drop, heat loading in the tunnel and routing congestion, the preferred choice was the three labyrinth design illustrated in Fig. 2.

When analysing the routing options for the dipole, the obvious solution is series connected cables installed next to the lattice, but this incurs stray EM fields near to the sensitive beam position monitoring equipment. The favoured route is the inner tunnel wall, which increases cable length by 78%, but reducing EM fields as these will cancel between wall and magnet. To reduce heat loading in the tunnel the option of routing cable outside the tunnel is also being investigated.

5 AC DISTIBUTION NETWORK

There is a maximum dc loading of 87kW for each of the 24 CIAs, provided by 60kW for quadrupole, 14kW for sextupole and 13kW for dynamic correctors. At nominal current the total dc power falls to approximately 50kW and with operating efficiency estimated at 80%, the total ac input power is 62.5kW.

The storage ring power converters are supplied from a dedicated ac distribution network, the point of common coupling to the general site distribution and to other external users is at 11kV. There will be four separate transformers, each feeding a quarter of the storage ring magnet power converters with an expected nominal loading of 0.4MW. This type of distribution will allow phase displacement of the transformers enabling the load to appear as 12 pulse or even 24 pulse configuration if required.

5.1 Harmonic Compliance

Before installation the expected harmonic levels must be calculated and gauged against the G5/4 UK Electricity Association recommendations. To estimate the harmonic currents drawn at the point of common coupling (11kV), the values of harmonic currents generated by a standard switchmode power converter, at a load similar to a quadrupole magnet, were measured and extrapolated. If the total ac load for all power converters with the exception of the dipole is approximately 1.5 MW, this equates to a phase current of 80 A at 11 kV. The results are shown in table 4.

Table 4: Six pulse harmonic currents

Harmonic Number	Current drawn at point of common coupling (rms per phase)	Limit in G 5/4 recommendation (absolute)
1	80 A	-
5	21.6 A	3.9 A
7	24 A	7.4 A
11	16 A	6.3 A
13	28.8 A	5.3 A

Table 5: Comparison of harmonic currents

Harmonic Number	Harmonic current absolute values		
	6 pulse rectification	12 pulse rectification	24 pulse rectification
5	21.6 A	4.96 A	4.96 A
7	24 A	7.28 A	7.28 A
11	16 A	16 A	0.8 A
13	28.8 A	28.8 A	8.0 A

These initial results show that even with 24 pulse configuration, compliance is still not quiet achieved.

Future investigation will be focused on whether filtering can be installed at source and the cost benefits analysed. This would also avoid the safety implications of phase displacement.

6 CONTROL SYSTEM

The transition from analogue to digital control of the regulation loop for a modern power converter is still developing. Six power converter designers were contacted and only two offered a fully digital solution. The others offered a digital interface, but with an analogue control loop, indicating that the majority of power converter companies are still reluctant to make the investment.

Issues relating to resolution and update rate (bandwidth) are mainly governed by the ADC or DAC, depending on which type of control system is used. The high resolution hinders the conversion speed and advances in this area will have to be investigated before the final specifications are produced.

Standardisation of the control system is difficult, without compromise the tender exercise and the quantity involved. An alternative is to use a dedicated power converter interface module like that employed at Spallation Neutron Source [2], which operates in conjunction with any standard analogue supply. This provides the intelligent processor as an external unit, simplifying the converter design.

7 THERMAL MANAGEMENT

Investigations into the optimum cooling method for different power ratings produced the results shown in Table 6. These indicate that the dipole is likely to be water cooled, sextupoles are suited to forced air and quadrupoles could employ either.

Table 6: Preferred method of cooling for designers

	Types of Cooling		
Magnet	Water	Forced Air	No preference
Dipole	5	-	-
Quadrupole	2	3	1
Sextupole	-	5	1

A direct water cooling system is a more economic method of removing heat from the power electronics. It also has the benefit of reducing volume, weight and makes it simpler to maintain constant ambient temperature. A disadvantage of using a water cooled system, is that not all the losses are removed and air conditioning at a lower level is still required.

Table7: Rack thermal loading

Suggested Rack layout			
Rack 1	Rack 2	Rack 3	Rack 4
Controls	Quad	Quad	Quad
Quad	Quad	Quad	Quad
Quad	Quad	Sext	Sext
Quad	Sext	Sext	Sext
	Sext	Sext	
3.15kW	3.85kW	3.15kW	2.8kW
Heat loading per cell		12.95kW	
Total heat loading for 24 cells		310.8kW	

The calculated losses for each CIA are 13kW. To dissipate this heat evenly the rack layout can be optimised as shown in table 6. These maximum thermal loading figures are based on 6kW quadrupoles and 2kW sextupoles with efficiency of 85%.

8 FUTURE DEVELOPMENTS

Before writing the specifications in January 2003 a full prototype evaluation is planned. This will include the loan or purchase of converters, which match the quadrupole and correctors requirements, to allow investigations into:

- Control – plant interface;
- Performance measurements;
- Environmental issues.

The procurement will commence April 2003 and orders will be placed by September 2003.

REFERENCES

[1] N. Marks et'al, "Design of quadrupole magnets for the DIAMOND synchrotron source", these proceedings.

[2] R.F. Lambiase, B. Oerter, S. Peng, J. Smith "Power Supply Control and Monitoring for the SNS Ring and Transport System", Proc. PAC, Chicago 2002.